Contribution of airborne remote sensing to high-throughput phenotyping of an hybrid apple population in response to soil water constraint

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Context: new traits in fruit tree species

Breeding of fruit species focusing on socio-agronomic traits:
- fruit quality,
- resistance to bioagressors,
- architecture features / regularity of bearing

} long-term validity *(Laurens et al., 2000)*

Global changes → new breeding traits: tolerance to drought and/or better water use efficiency (WUE) *(Regnard et al., 2009)*

Phenotypic trait privileged: scion variety leaf response
Variability of stomatal behavior in young apple trees *(Massonnet et al., 2007 ; unpublished results)*

High-throughput methods needed for further genetic study *(Berger et al., 2010)*

Context: leaf temperature & stress indices

Leaf temperature (infrared thermometer / thermal IR imaging)
→ indicator for plant water status in annual crops and g_s estimation *(Jones et al., 1999)*
→ irrigation scheduling via different water stress indices: Crop Water Stress Index (CWSI) based on T_s-T_a variation *(Idso et al., 1981)*

CWSI validity *(Jackson et al., 1981)*:
- continuous cover,
- semi-arid and arid conditions,
- time-series available

Adaptation of CWSI to discontinuous cover *(Moran et al., 1994)*
Water Deficit Index (WDI) using $T_{s'}$ -T_a variation plotted against NDVI;
→ potentially applicable to fruit trees in field conditions?

Context: multispectral imaging approaches

Multispectral plant imaging (RGB, Red Edge, NIR, TIR, fluorescence):

- controlled conditions

  Lab diagnosis of stress response *(Chaerle et al., 2000)*

  High-throughput phenotyping facilities *(Berger et al., 2010)*

- field

  Monitoring water stress / scheduling cultural practices
  - Annual crops (*Lebourgeois et al., 2010)*
  - Perennial crops *(Sepulcre-Cantó et al., 2006; Grant et al., 2007)*

  Phenotyping plants for differences in stomatal behavior *(Jones et al., 2009)*

Methodological & scientific aims

Use multispectral imaging for phenotyping an apple hybrid population in field

Hypotheses :

1 : High-resolution imaging at tree scale (through airborne RGB / NIR / TIR imaging) → relevant solution for phenotyping plant canopy T° variations

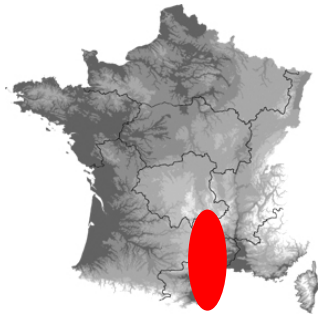
2 : HR imaging + stress index → sensible method for discriminating plant stomatal response to water stress (disentangling isohydric *vs* anisohydric behaviors)

Experimental set-up

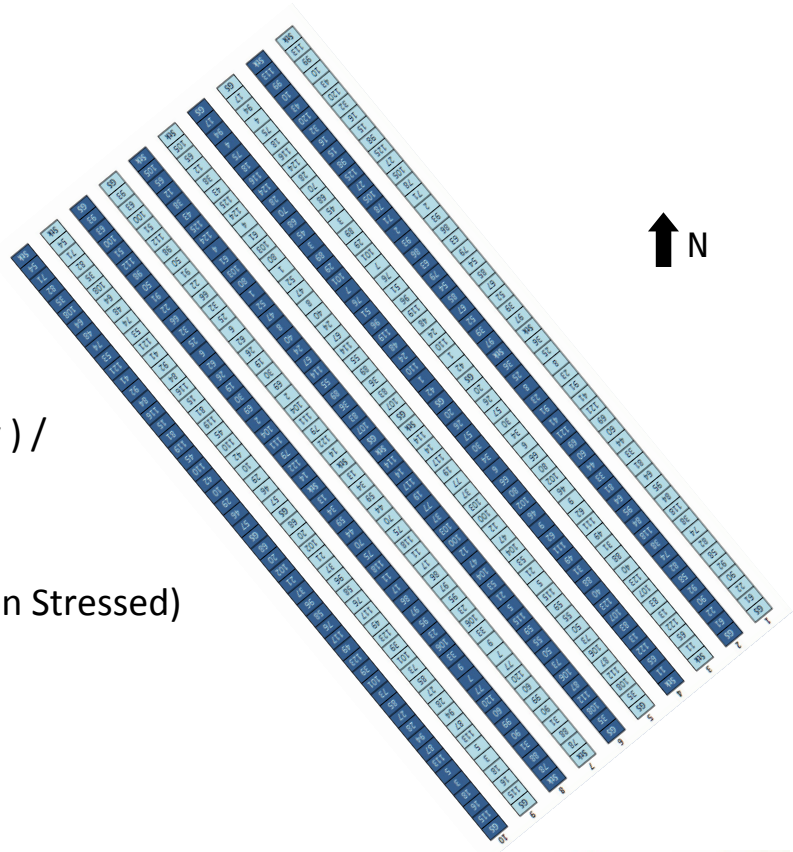
1. Location

INRA-Diaphen
Melgueil exp^{l} farm

(43°36’35 N,
3°58’52 E)



Not irrigated during summer (S)
Always irrigated (NS)



2. Field set-up

- **488 apple trees**
- **122 hybrids** (Starkrimson * Granny Smith progeny) / M9 roostock ; + parents
- **10 rows**
- **2 seasonal water treatments : S, NS** (Stressed, Non Stressed)
- **2 replicates**

Trial description

3. Environnemental and agro-physiological measurements

Meteorology and soil

- Global radiation, Direct & diffuse PAR,
- Soil & air T°, air RH
- Wind speed
- Precipitations
- Soil analyses
- Soil water content (Sentek capacitive sensors)
- Soil water potential (Watermark^{TM} probes)
- Field resistivity mapping (Geocarta)

Agronomic data

- Individual tree crop
- Trunk diameter and section
- LAI, SPAD (5 hybrids subset)

Ecophysiological data

- Predawn leaf water Ψ
- Minimum stem water Ψ
- Photosynthesis rate (A/Ci)
- Chlorophyll fluorescence
- Canopy T° (non-imaging)
- Stomatal conductance

} 3 to 5 hybrids

- Leaf and/or fruit $\Delta^{13}C$ (proxy of WUE)

agap

International Plant Phenomics Network IPPN

High resolution remote sensing 2010 campaign

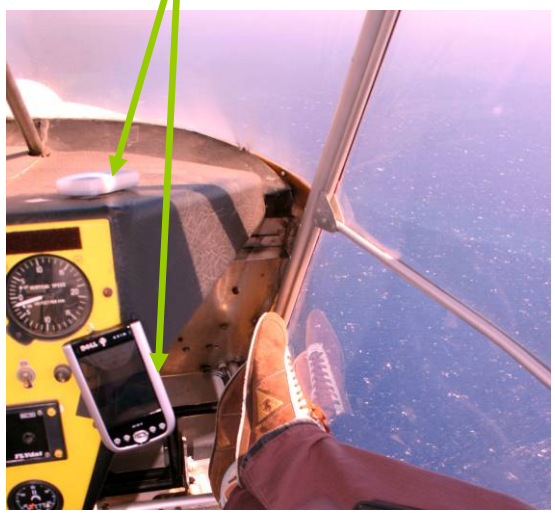
1. Acquisition system

RGB and NIR cameras (Canon EOS 400D)

L'AVION JAUNE

300m

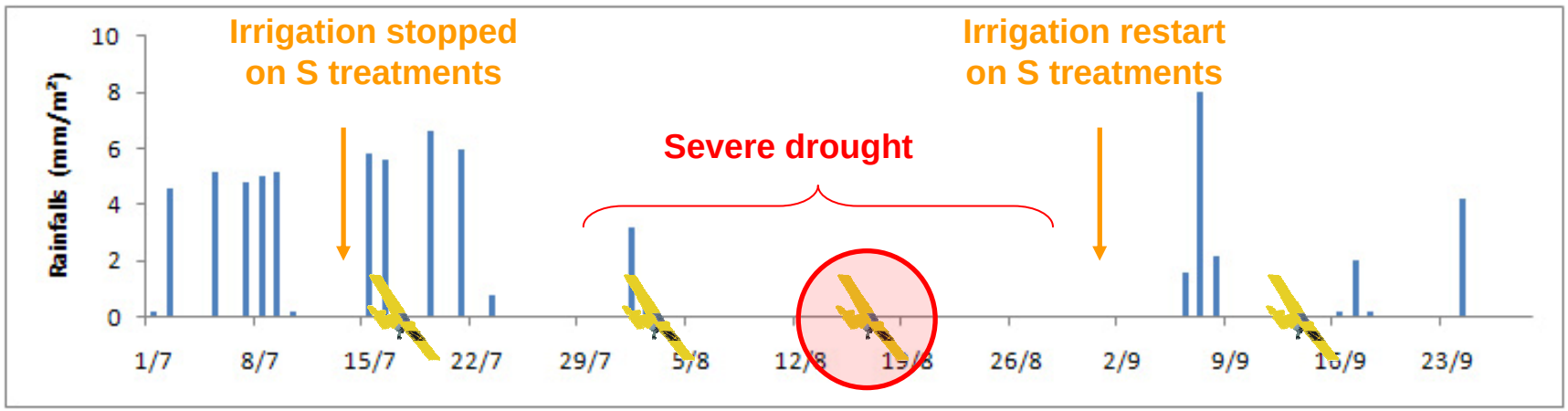
GPS + PDA (Altitude / Location) + T_a and HR sensors



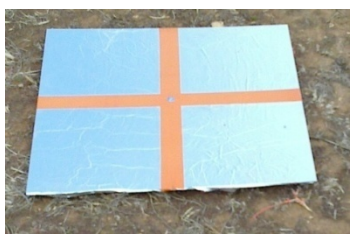
Thermal IR camera (Flir B20HSV, 320*240px)

High resolution remote sensing 2010 campaign

2. Airborne imaging over the trial



4 ULA flights (RGB, NIR, TIR) coupled with ground measurements:

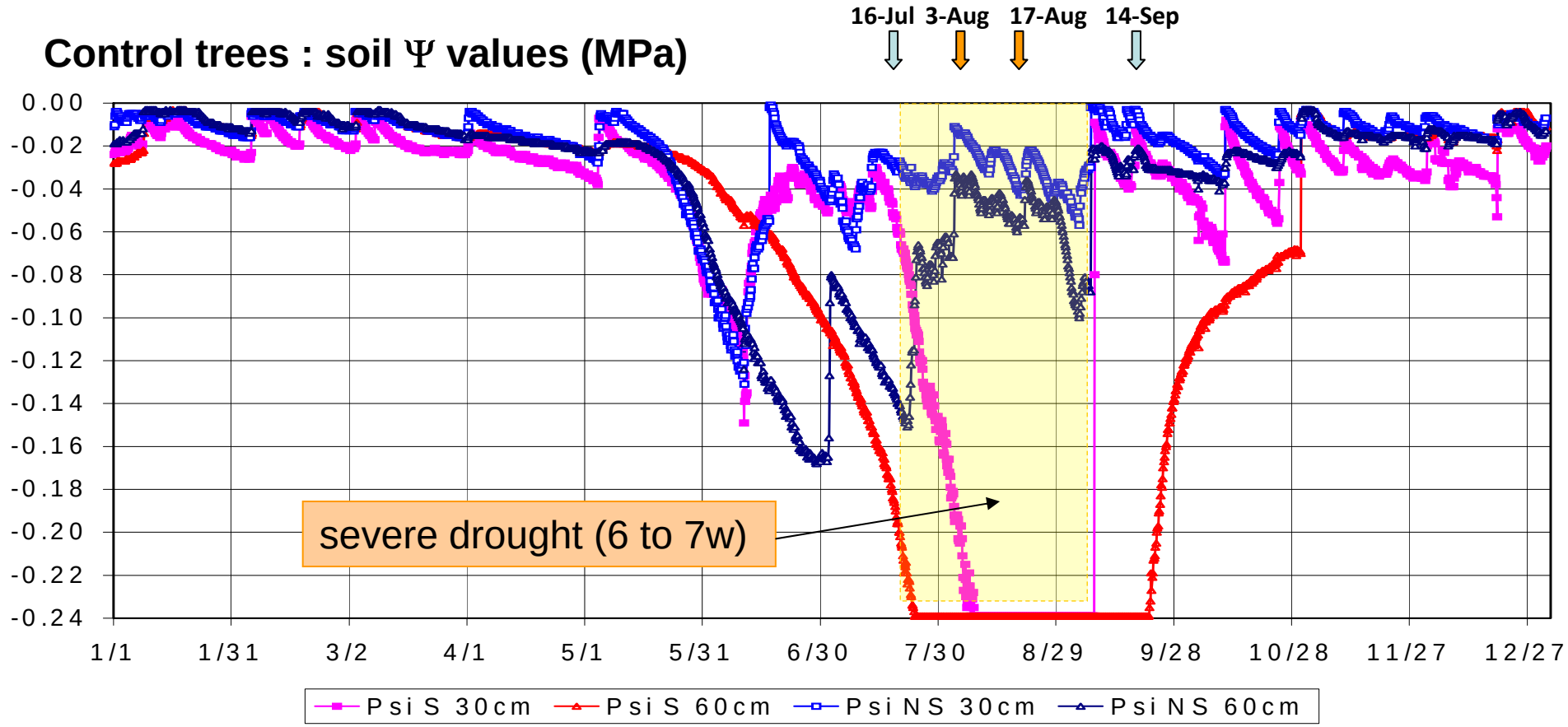


Aluminium targets (for TIR images geolocation)

Thermal Infrared thermometer KT19 Heitronics® [8 – 14] µm measurements on hot and cold targets

Water stress scheduling

Control trees : soil Ψ values (MPa)



Parallel measurements: predawn LWP, soil humidity (Sentek probes)

Image processing & indices

3. RGB and NIR images → four spectral bands

1. Blue

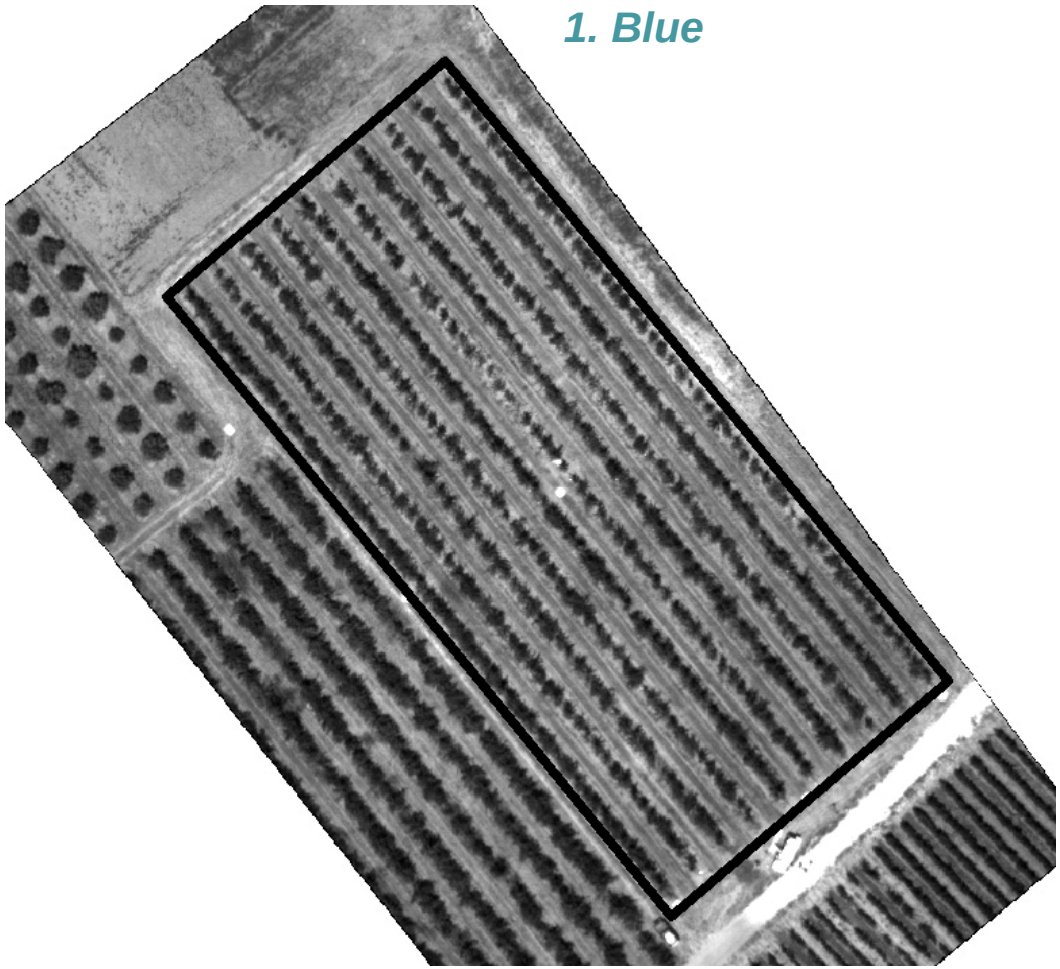


Image processing & indices

3. RGB and NIR images → four spectral bands

2. Green

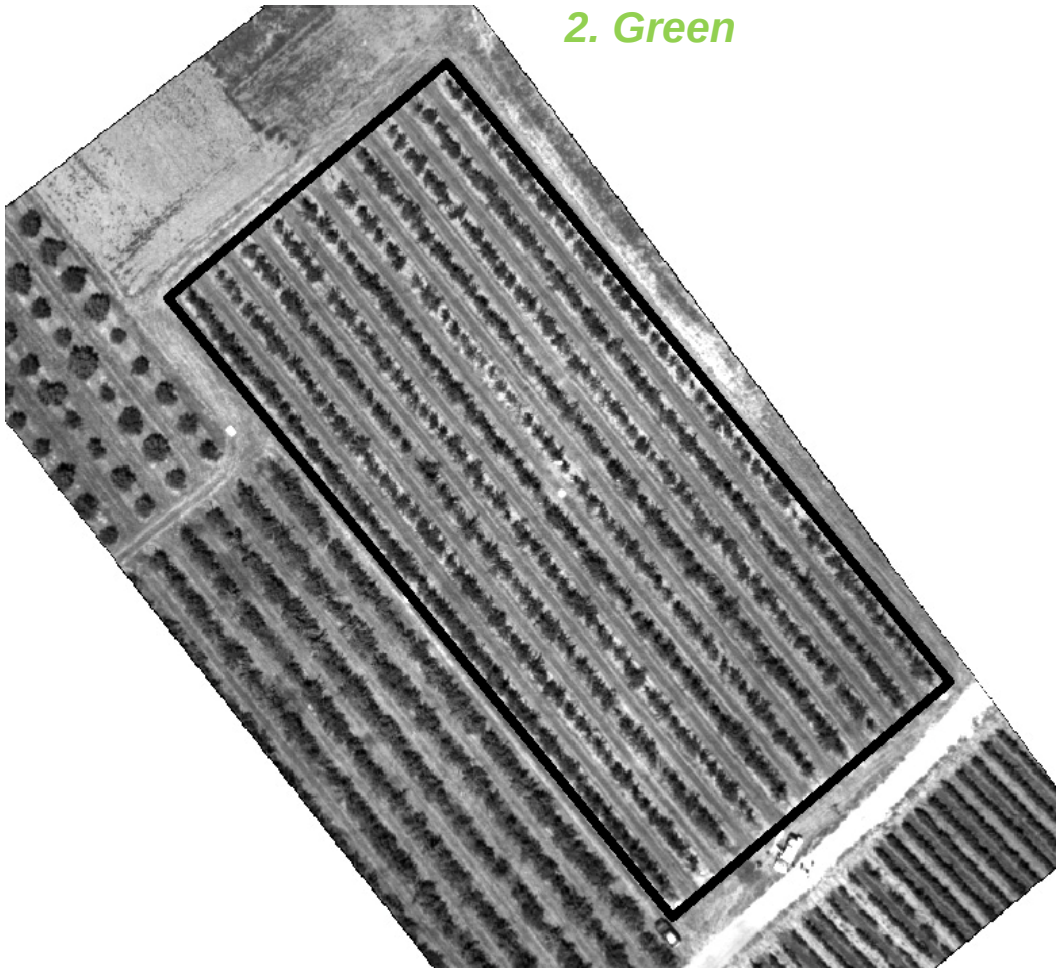


Image processing & indices

3. RGB and NIR images → four spectral bands

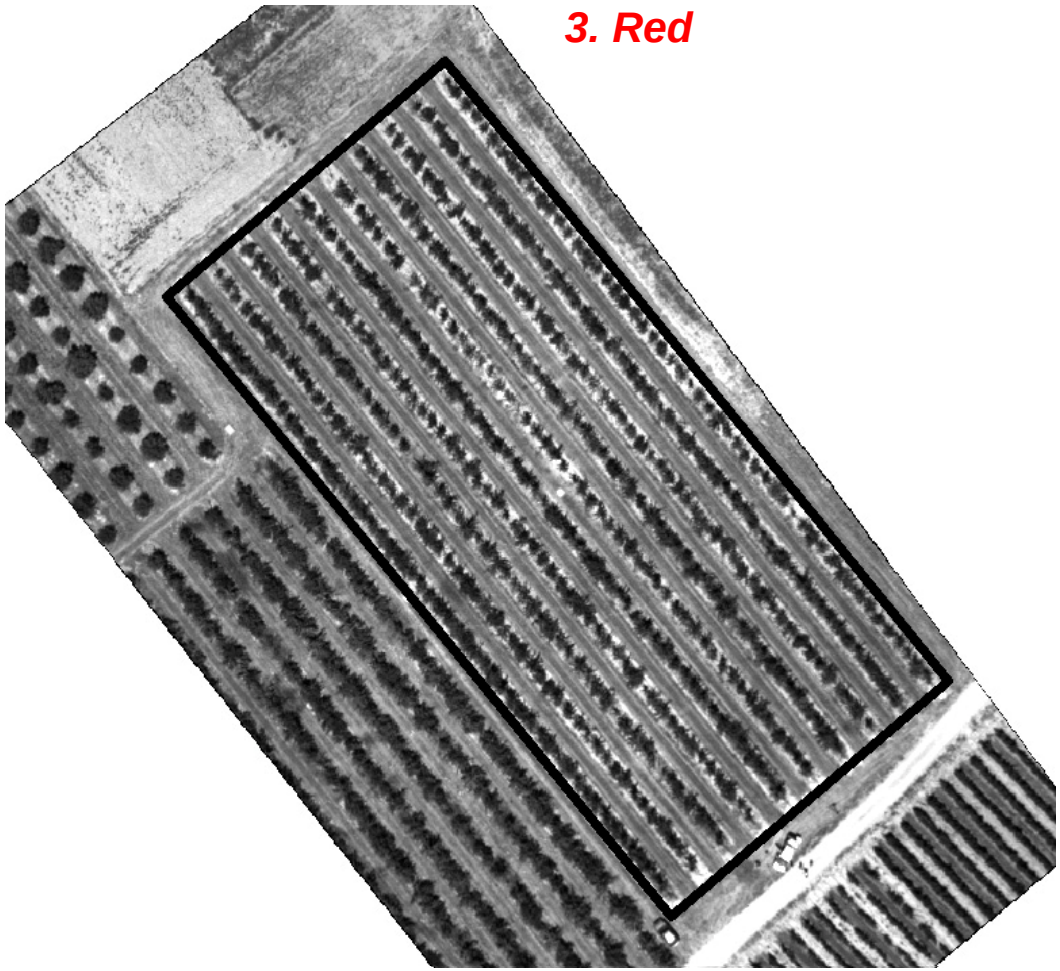
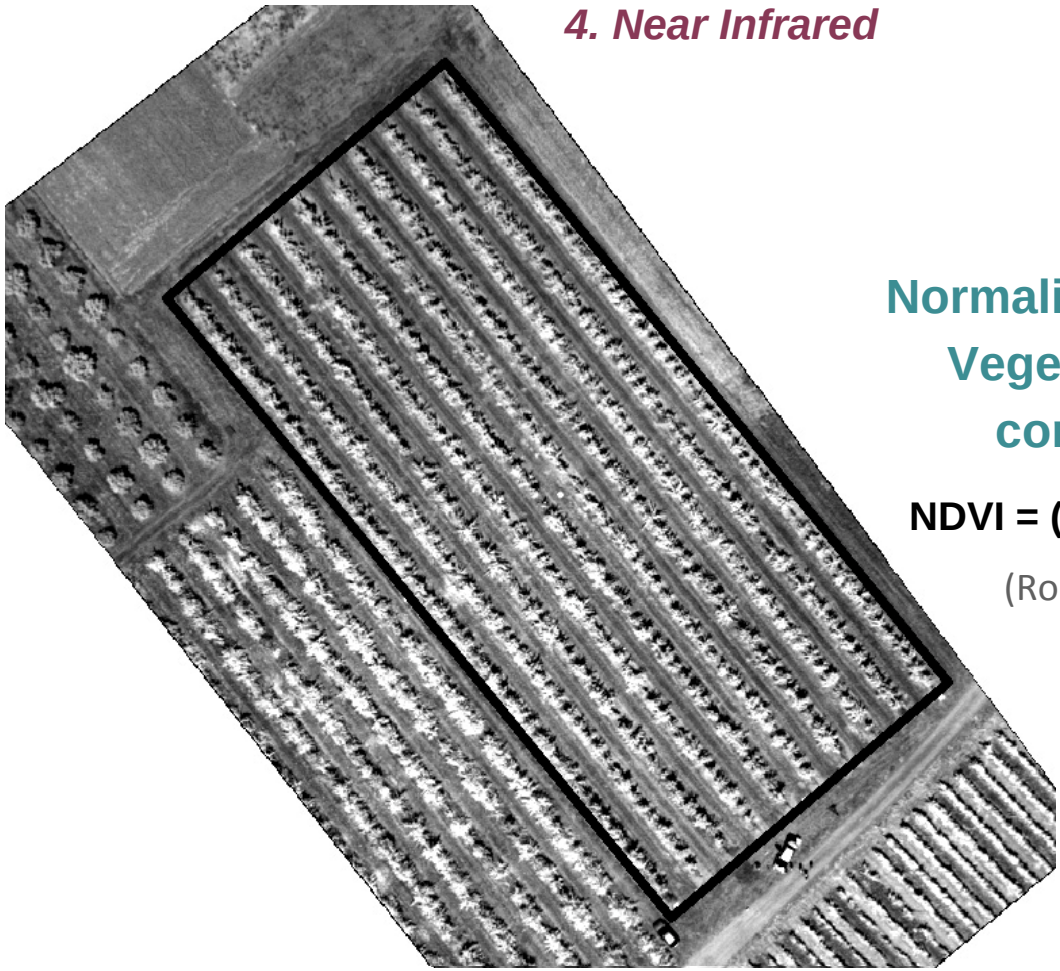


Image processing & indices

3. RGB and NIR images → four spectral bands

4. Near Infrared



Normalized Difference Vegetation Index computation

NDVI = (NIR-R) / (NIR+R)

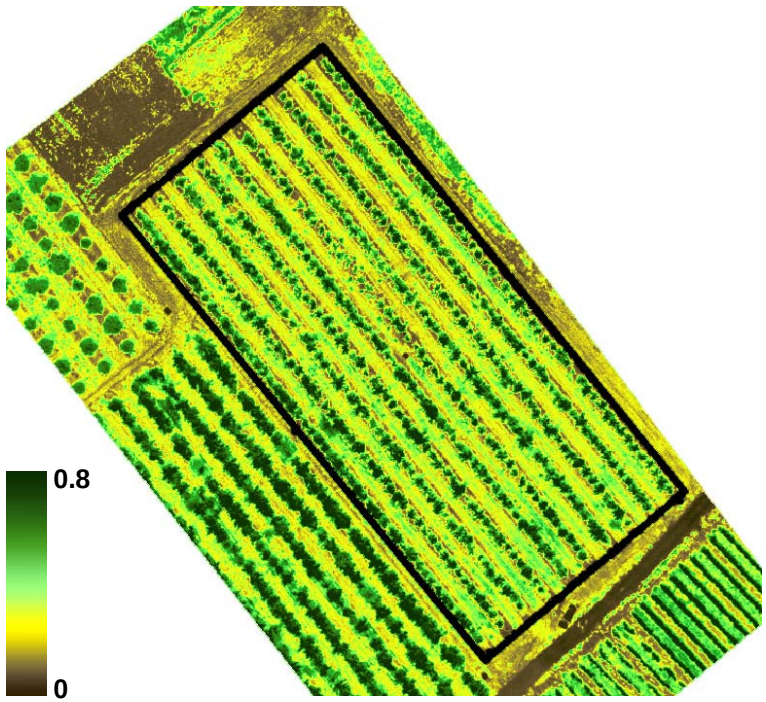
(Rouse et al., 1973)

Image processing & indices

3. Vegetation Index

NDVI = (NIR-R) / (NIR+R)

NDVI image



4. Thermal IR image (T_s-T_a)

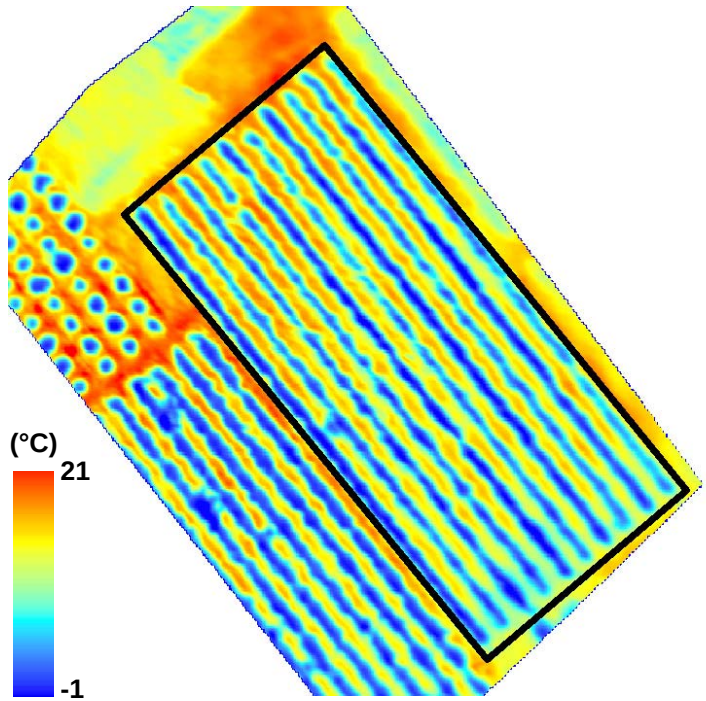
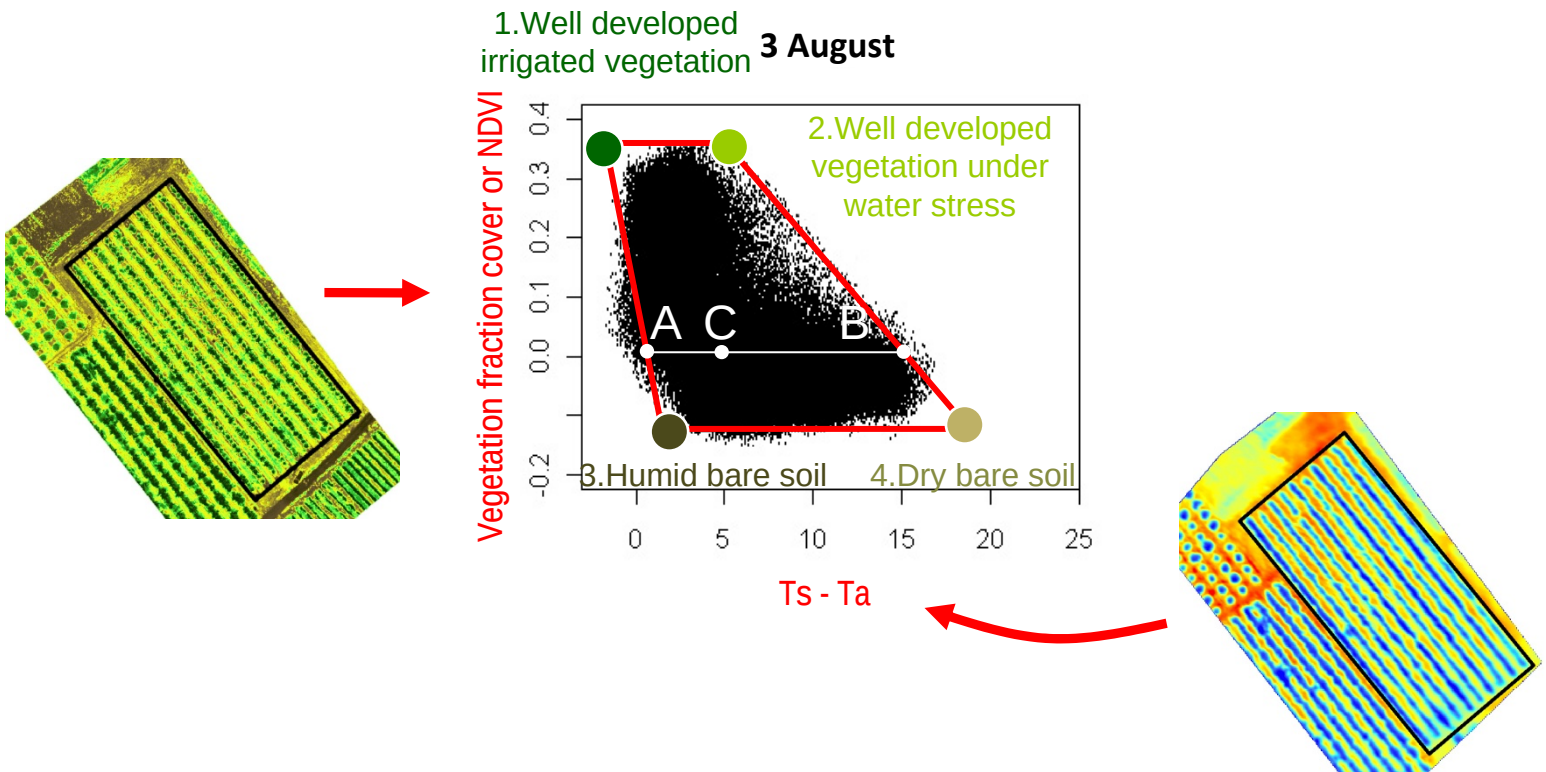


Image resolution: RGB / NIR : 5cm ; TIR : 30cm

Image processing & indices

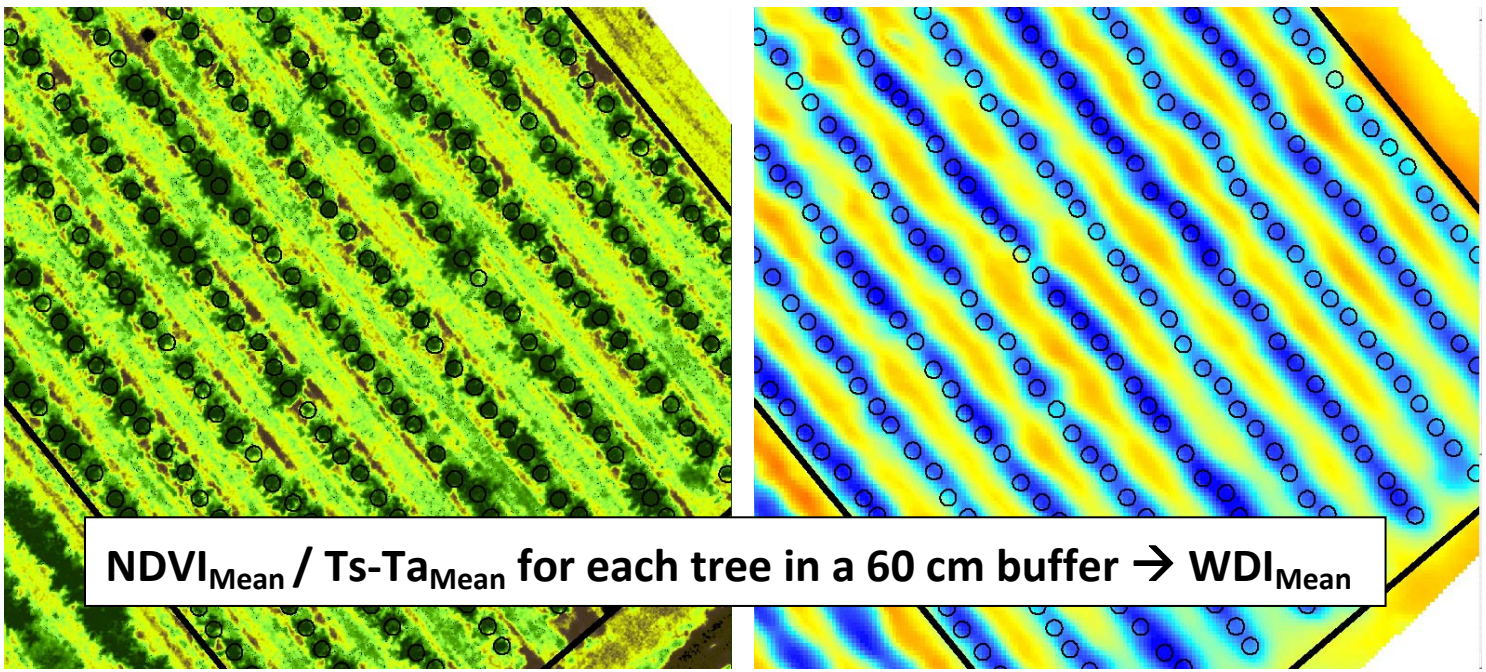
5. Water Deficit Index (Moran et al, 1994)

WDI = 1 – (ET_{Act} / ET_{Max}) = AC / AB
Designed for partially covering crops



Delimitation of tree canopies

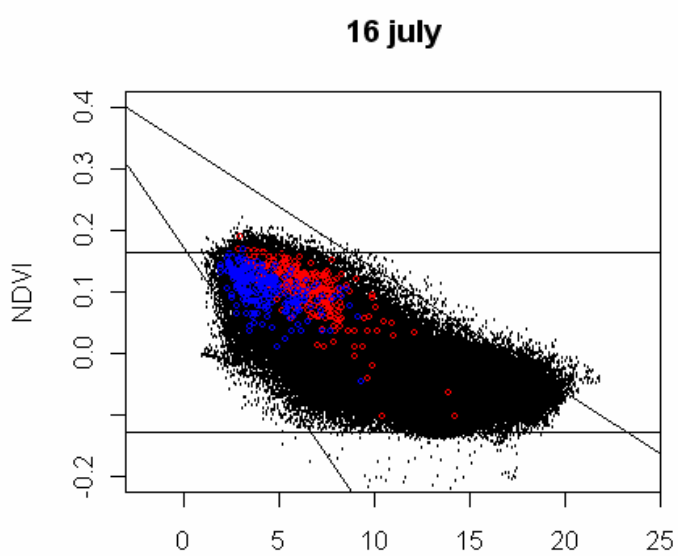
6. NDVI-based location of each tree central zone

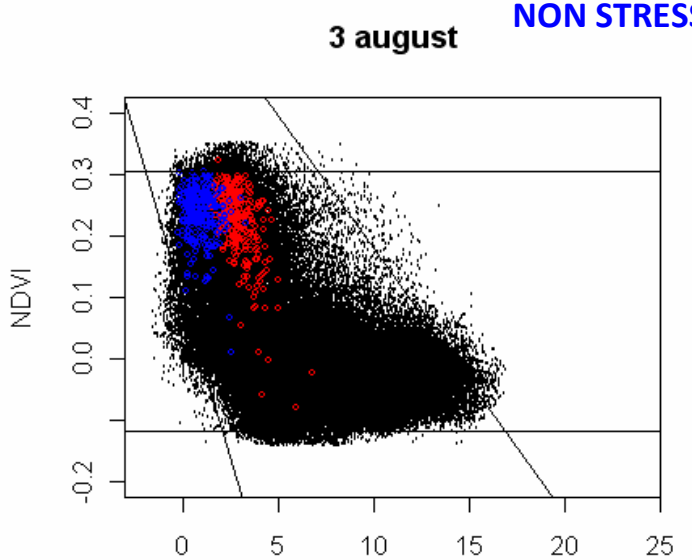


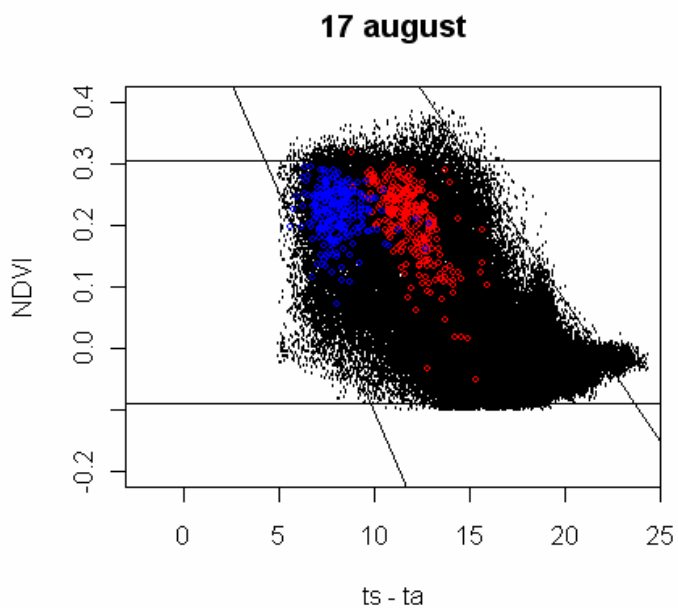
$NDVI_{Mean}$ / $Ts\text{-}Ta_{Mean}$ for each tree in a 60 cm buffer → WDI_{Mean}

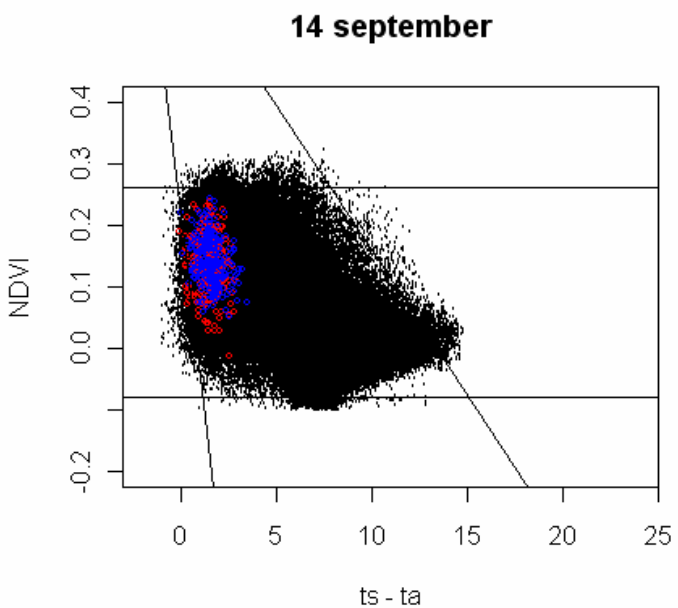
Preliminary results: Water Deficit Index

STRESSED trees
NON STRESSED trees









Preliminary results: Genotype & Drought effects

2-way ANOVA applied to WDI values (2010 campaign)

Effect		07-16	08-03	08-17
Genotype	*F* *p* -value	1.8 $<10^{-4}$	1.9 $<10^{-4}$	1.5 $<10^{-2}$
Drought	*F* *p* -value	501 $<10^{-6}$	772 $<10^{-6}$	1661 $<10^{-6}$
G * D	*F* *p* -value	0.5 p# 1.0	0.5 p# 1.0	0.6 p# 1.0

n.s. effects on Sept 14

Contrainsts & limits

- Field meteorological constraints
- « Snapshot » datasets (which potentiality to reveal contrasting behaviors?) ;
- Current TIR image resolution: 30 cm
- Atmospheric corrections: $T°_{\text{Top of canopy}}$ needed (non imaging thermoradiometers; thermic transfer model)
- Assessment of NDVI variations resulting from other factors than LAI and soil cover fraction (leaf chlorophyll and N content)
- Computation of WDI trapezoid envelope: information of satellite images

Methodological & scientific challenges

- Flight program continued (2011-12)
- Proxi-imaging: methodological aspects (on a tree population subset) and image analysis *(Cohen et al., 2005 ; Möller et al., 2007)*
- Assessing the resolution of airborne remote sensing *vs* proxi- TIR images:
- Relevancy of other Water stress indices, e.g. S-Sebi *(Roerink et al, 2000)*
- Field validation of water stress index with apple tree water status

- Robustness of leaf traits: greenhouse (young stage) *vs* field (maturity stage) ; phenotyping young trees on the PhenoArch high-throughput facility (2013)

- Cluster analysis of hybrid apple progeny on the basis of WDI and other criterions (leaf and/or fruit $\Delta^{13}C$)

- Heritability analysis on functional traits, QTL detection and more refined genetic studies related to QTL zones

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